A NOVEL METHOD FOR MEASURING ENERGY LOSS IN ELECTRON RINGS*

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Abstract

We present a novel method for measuring the energy loss per turn in an electron storage ring. The method involves the accurate measurement of the change in the rotation period of an uncaptured electron bunch using a dual-sweep streak camera. In our opinion, this method is more direct and accurate than other techniques. We present examples of measurements performed at the Advanced Light Source.

1 INTRODUCTION

During our studies of longitudinal injection transients described in Ref.[1], we had occasion to observe the decay of the beam with the RF system turned off. In such a situation it is impossible to store beam for longer than a few tens of a millisecond. However, we realized the application of this observation as a technique to measure the energy loss per turn due to synchrotron radiation and potentially some other interesting machine parameters. Although it is possible to measure the energy loss per turn in other ways, we believe this technique is the most direct and accurate, given the availability of a dual sweep streak camera (Hamamatsu C5680).

We describe this technique below and give an example of its application at the ALS.

2 DECAYING BEAM TRANSIENT

When an electron bunch is injected into the storage ring with the radiofrequency (RF) power turned off, it begins to lose energy to synchrotron radiation. Its orbit spirals inwards and the beam eventually hits an aperture and is lost. The ring orbit period also varies according to the relation:

$$\frac{\Delta T}{T_0} = \alpha_p \delta_{tot} \tag{1}$$

where α_p is the momentum compaction, and δ_{tot} is the total fractional energy difference of the beam from the injected energy. Above transition, we expect the orbit period to decrease with time when the beam energy is decreasing (α_p>0 and δ_{tot}<0).

Immediately following injection, we can assume the energy loss per turn is constant and α_p is independent of energy. In this case the total path difference (in units of time) can be expressed as:

$$\Delta T_{tot} = \frac{f_{rev}}{2E} \alpha_p U_0 t^2 \tag{2}$$

where t is the time following injection, U_0 is the energy loss per turn, E the ring nominal energy and f_{rev} the revolution frequency. The quadratic dependence of the path difference on time results from integrating the linear energy difference per turn.

Equation (2) suggests that, if one is able to measure the total path difference, it is possible to measure the energy loss per turn, all other parameters being known.

Alternatively, if it is possible to measure the energy loss per turn by other means, the method is suitable for measuring the momentum compaction.

3 EXPERIMENTAL SETUP

We inject a single bunch of about 0.25 mA from the 1.5 Gev booster ring into the main storage ring with the RF power set to zero. The injection rate is 1 Hz and we target the same RF bucket so that it is possible to average over several injection cycles in order to improve the signal-to-noise ratio.

The streak camera is at the end of our beam physics dedicated beamline where the synchrotron light originates in one of the bending dipole magnet. Its fast vertical deflection plates are driven by a 125 MHz sinusoidal voltage synchronized to the 500 MHz RF frequency (synchroscan), while the slower horizontal sweep has an adjustable scale to observe from a fraction of a turn up to a few thousands of turns.

The injection process timing in the ALS has direct consequences on our ability to take data and , in particular, to average over several injection shots so we will briefly illustrate how we had to implement sofware changes to obtain data right at the injection.

When the booster ring magnets have reached their nominal values for 1.5 GeV, an end-of-ramp signal is generated. The control system then waits for the first occurrence of the coincidence clock, that is when bucket zero of booster and storage ring are aligned. Injection in the targeted RF bucket is insured by a look-up table where the number of storage rings cycles to wait following the coincidence clock is recorded.

Unfortunately, none of the two available trigger signals (end-of-ramp and coincidence clock) was suitable for our application: the time lag between end-of-ramp and actual injection is not fixed or it is too short (such as the first 200 μs after injection are lost) if the coincidence clock is used instead. Our solution was to modify the look-up table allowing for an extra delay to be added.

Finally, we want to point out that, because of the way the synchroscan operates, when the turn-to-turn path length difference is converted to a sinusoidal vertical deflection,

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the data taken near the synchroscan crests is lost as it falls out of the microchannel plate acceptance. This also can distort the measured drift as it will be pointed out in Section 4: as the bunch arrives earlier each turn, we will observe an increasing vertical deflection on the streak camera until the path length difference is larger than a quarter wavelength of the synchroscan frequency whereupon the vertical deflection will decrease. This is illustrated in Fig. 1.

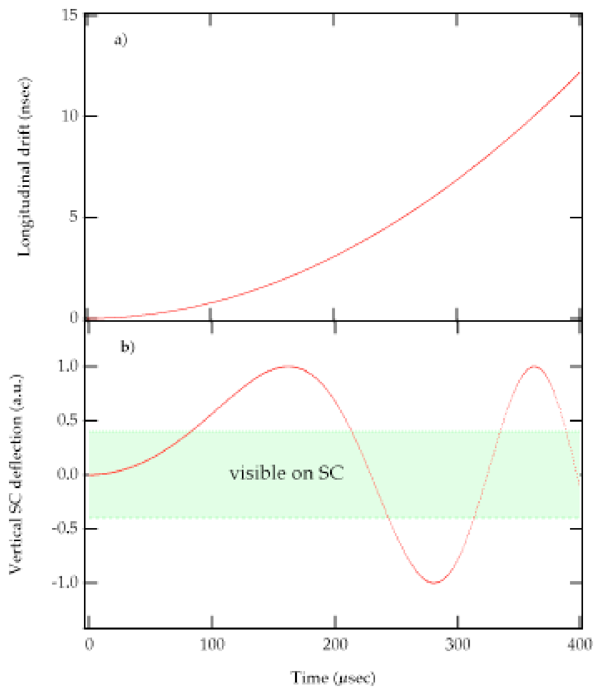

Figure 1. Vertical deflecting voltage shown with respect to the longitudinal drift (i.e. arrival time) of the injected bunch. Only deflection withen the marked band are observed

4 EXPERIMENTAL RESULTS

Figure 2 shows a streak camera image at injection with the storage ring RF turned off and all the insertion devices gaps open. An expanded view of the first 120 μs is shown in the lower image on which a fit of the orbit period difference using Eq.(2) is also shown as a superimposed white line. This gives a value for the radiation loss per turn of about 94 keV, close to the expected value of 92 keV.

It is also possible possible to derive more information from the evolution of the bunch length and we are currently analyzing this.

We have repeted this process taking streak camera images for different positions of the ring insertion devices. The ALS features a wiggler, with a minimum gap of 13 mm, and six undulators.

We took several pictures in correspondence of different gap positions. As an example, Fig. 3 displays the fitting curve to the images taken with all the insertion devices open, except for the wiggler, which is closed down to a 24 mm gap. Note the improved signal to noise ratio compared to Fig. 2 since, we the new software, we were able to average over 5 consecutive injection cycles.

The fitting curve (continuous white line) corresponds to an energy loss per turn value of about 154 keV. AS a reference we also show the fit (dashed black line) relative to the nominal energy loss per turn of 92 keV.

In principle, to fit the data the sinusoidal deflection of the vertical sweep should been taken into account as:

$$fit(t) = t_0 + t_{\max} \cdot Sin\left[\frac{2\pi \cdot c_x \cdot t^2}{T_{vert}}\right] \quad (3)$$

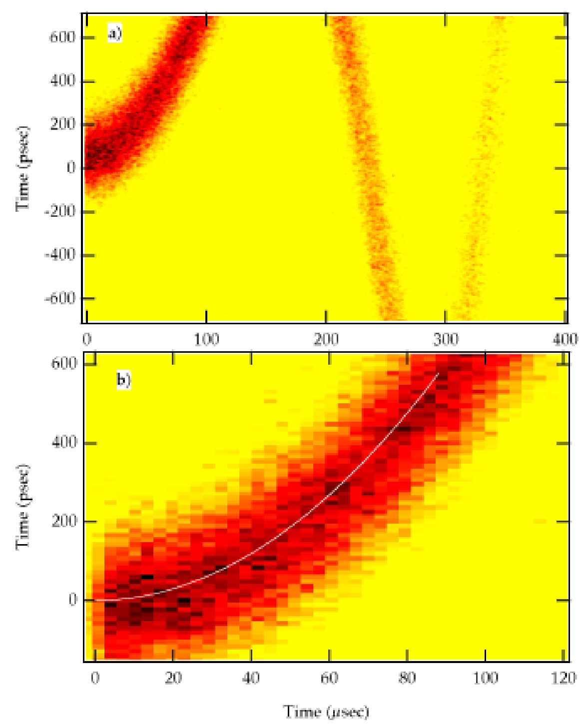

Figure 2. Streak camera images of a decaying, uncaptured electron bunch at injection. A fit to the drift is shown as a white line on the lower image.

where t_0 is the arbitrary vertical deflection at injection, t_{max} its oscillation amplitude, T_{vert} its period and c_x is proportional to the energy loss per turn.

Comparing Eqs.(2) and (3), we have:

$$U_0 = c_x \frac{2E}{\alpha_p f_{rev}} \quad (4)$$

In practice, if we just consider the first few tens of ms after the injection (that is, $t << T_{vert}$) we can neglect the sinusoidal modulation of the measured time offset, still mantaining a good approximation.

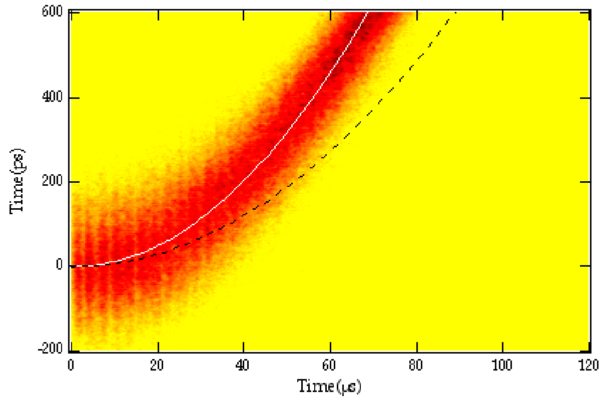

Figure 3. Streak camera image of an uncaptured bunch with the wiggler gap set at 24 mm opening. A fit to the drift is shown as a white line ($U_0 \approx 154$ keV). The dashed black line corresponds to the nominal energy loss per turn of 92 keV.

5 CONCLUSIONS

We have presented experimental observations of the beam decay, when no radiofrequency power is applied to the ring, as observed on a streak camera.

The analysis of the images taken allowed us to extract the energy loss per turn from the motion of the center of charge of the injected bunch, thus allowing for a direct measurement of this important parameter.

The technique described in this paper has been applied to the Advance Light Source storage ring and the change in the energy loss per turn with different insertion devices gap openings has been measured.

6 ACKNOWLEDGEMENTS

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7 REFERENCES

[1] J. M. Byrd and S. De Santis, "Longitudinal Injection Transients in an electron Storage Ring", *Phys. Rev. ST - Accel. Beams* ***4****, 024401* (2001).